Case study of ISWI in Vietnam: A comparison of ionospheric parameters observed over Ho Chi Minh with IRI predictions

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Abstract: For the contribution of Vietnam to ISWI activities, there are 3 GPS receivers, 3 Ionosondes, 1 AWESOME and 1 MAGDAS operating in Vietnam. With a special geographical position stretching from the north tropic to the magnetic equator, Vietnam is an interesting area to supplement the data for the Global Space Weather Model. The Ionosphere is an important indicator of Space Weather and the International Reference Ionosphere (IRI) model has become widely accepted. The first task of ionospheric science in a new location is often comparing the observed data with IRI.
This paper presents the results of comparisons of the foF2 and TEC observed over Ho Chi Minh City (10.51 N, 106.33 E) with the values calculated according to the IRI-2007 in order to evaluate the applicability of the model in forecasting for the equatorial region of Vietnam. We compare the critical frequency of layer F (foF2) and Total Electron Content (TEC) values for two phases of solar activity. The results show very good diurnal correlations between the observed foF2 and TEC with IRI values in the decreasing solar activity period 2003 – 2006 (the deviation < 15%). In the increasing period 2009 – 2012, good correlation was in the morning time before the foF2 peak at about 10 LT, with a deviation about 10% (except 2012). However, after 10 LT, the IRI-foF2 values rose up and the deviations were about 25% to 30%, especially during evening. In the years with low solar activity (SSN < 40), the IRI-foF2 are almost always higher than the observed foF2 data and vice versa for the years with SSN > 40. This is a note for correction IRI model applying for Vietnam. The comparison of the TEC shows that the correlation between GPS-TEC and IRI-TEC generally was good with coefficients k > 0.8 and R > 0.9 for the period 2006 - 2010. The worst relationship were March, April, September, October, November and December 2011, corresponding to periods when the TEC gradients are highest. The phenomenon of decline in the TEC at noon over Ho Chi Minh City observed pretty weak. This phenomenon appeared only in a few months from April to September, when the ionization is high. In the period from 0 to 5 am local time, the average minimum GPS-TEC observed over Ho Chi Minh City is about 3 tecu, while the IRI-TEC value is ~ 0.3. Thus, the IRI-TEC values should be recalibrated.

Keywords: Ionosphere, IRI Model, Total Electron Content, critical frequency.

Introduction

Vietnam is a country with an interesting geographical position that stretching from the north tropic to the magnetic equator (23.36 N – 8 N) and in longitude from 102 E to 110 E. During past decades, many different instruments have been set up and separate ionospheric and magnetic studies have been carried out in Vietnam (Hoang Lan, 1983; L. Hoang et al., 1984, 1985; K.B. Serafimov et al., 1985; Truong Quang and Le Huy, 1987; Hoang Thai Lan et al., 1997 – 2011; Le Huy Minh and Pham Van Tri, 2001; Le Huy and Amory-Mazaudier, 2005; C. Amory-Mazaudier et al., 2006; Sahai et al., 2005, 2009). Figure 1 presents the Vietnamese network of instruments. There are 4 magnetic observatories in Vietnam: Sa Pa (22.33 N, 103.83 E) and Phu Thuy (21.03 N, 105.95 E in the North, Da Lat (11.95 N, 108.48 E) and Bac Lieu (9.28 N, 105.73 E) in the South. There are 3 GPS Receivers in Vietnam. They have been installed in Phu Thuy, Hue (16.40 N, 107.40 E) and Ho Chi Minh (10.88 N, 106.55 N) in 2005. In Ho Chi Minh City a CADI (Canadian Advanced Digital Ionosonde) is operating since 2000. In Phu Thuy, ionosondes operated from 1963 to 1998. Since 2006, 2 ionosondes from the SEALION project were installed in Ha Noi and Bac Lieu. ISWI instruments are AWESOME and MAGDAS. In 2009, a MAGDAS 2 was installed in Bac Lieu and in March 2012, the Kyushu University upgraded the MAGDAS 2 to a MAGDAS 9. In November 2011, an AWESOME Receiver was installed in Nha Trang. The instruments network and studies give us abilities to participate in the international programs involving Sun-Earth connections today.

As the Ionosphere is an important indicator of Space Weather, this report focuses on the comparison of the ionospheric parameters observed over Ho Chi Minh (HCM) with the International Reference Ionosphere (IRI) Model predictions. We presents the results of the comparisons of the foF2 parameter collected by a CADI (Canadian Advanced Digital Ionosonde) and TEC obtained by the dual frequency GPS receiver with IRI predictions. The IRI model was initiated by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI) in the late 1960s with the goal of establishing an international standard for the basic parameters of the ionosphere, based on ground monitoring of data in many parts of the world and the satellite data. The IRI model has been steadily improved with newer data and with better mathematical descriptions of global and temporal variation patterns. The IRI model has become widely accepted recently so that the first task of an ionospheric science in a new location is often comparing the observed data with IRI (Rawer 1978; Bilitza and Rawer, 1996; Bilitza, 1990, 2001, 2008).

Previous studies comparing the IRI-2001 model with observed data in the equatorial region was carried out by many authors such as A.O. Ologunleko et al (2000) with observational data at equatorial station Ibanda (7.4 N, 3.9 E), RT. De Medeiros et al (2003) observed in Natal (5.2 S, 36 W) near the solar cycle maximum and compared with IRI for quiet and disturbed conditions. P.K. Bhuyan et al (2006) measured TEC using receivers at 18 sites in India in 2003 and 2004 to study the variation in daily, seasonal and annual variations of TEC and compared with model IRI-2001. The research results have been updated to the IRI-2007 version. To determine the accuracy of the IRI model for the equatorial region of Vietnam, this paper presents the results of comparing the values observed over Ho Chi Minh (HCM) and the values calculated from the IRI-2007 model (http://omniweb.gsfc.nasa.gov/vitmo/iri_vitmo.html). The results allow us to consider the suitability of the IRI model for the equatorial region of Vietnam, and also to improve the model.

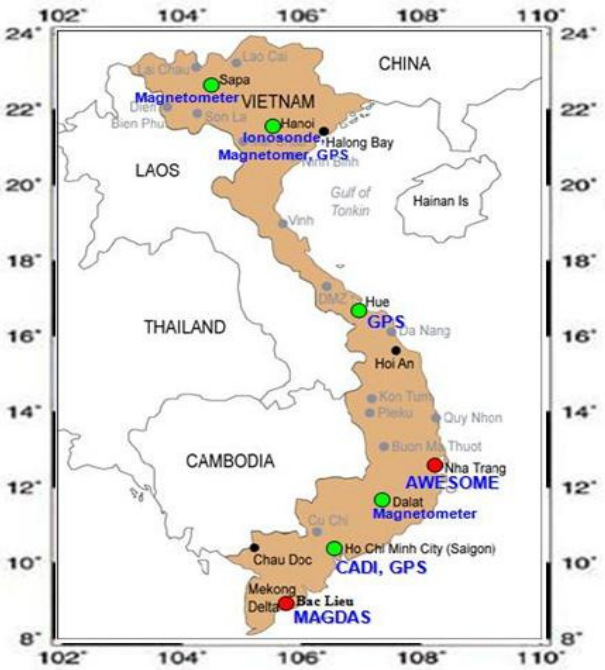

Figure 1: Map of the Vietnamese network

Data and method of analysis

The selected period for this study is from 2003 to 2012. The average sunspot number (SSN) as follows: 2003 = 63.7, 2004 = 40.4, 2005 = 29.8, 2006 = 15.2, 2007 = 7.5, 2008 = 2.9, 2009 = 3.1, 2010 = 16.5, 2011 = 55.7, 2012 = 55.7 (www.sidc.oma.be/sunspot-data/). The decreasing phase of solar activity is from 2003 to 2008 and the increasing is from 2009 to 2012.

The data used in this work were obtained by the CADI and dual frequency GPS receiver at observatory Ho Chi Minh (HCM). The CADI was calibrated regularly by its author (Prof. John W. MacDougall). The CADI data (from 2003 to 2012) was scaled from ionograms and averaged to obtain specific critical frequency foF2 of local time (LT) hourly, daily and monthly. The GPS data (from 2006 to 2012) calculated vertical Total Electron Content (vTEC) of local time hourly, daily and monthly. TEC data with satellite elevation angles less than 30^{0} are excluded to reduce the effects of the ionosphere.

Using the IRI-2007 model, the TEC was calculated taking values of atmospheric boundary for TEC as 2000 km. Output data was calculated for each hour of days from 2003 to 2012.

The Correlation Coefficient (R) and slope of the fitting line (k) between observed data and IRI calculated values used the equations:

$$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad [1]$$

$$k = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad [2]$$

$$b = \bar{y} - k\bar{x} \quad [3]$$

Where x is CADI data (or GPS-TEC) and y is IRI values, $\bar{x}$ and $\bar{y}$ are respective their average values, and n is the number of them. The compatibility of the two data sets is higher when the value R is close to 1. The linear relationship between x and y is y = kx + b. Coefficients k and b are calculated as above. Best agreements is when k ≈ 1 (k > 1 shows that the values calculated by IRI model is higher than the monitoring data, and vice versa).

Results and Discussion

The results of the comparision between observed foF2 and IRI-foF2

Figure 2 illustrates the comparision of diurnal variations between CADI-foF2 and IRI-foF2. The solid curves present the averaged observed foF2 and the dotted curves present the calculated foF2 values from IRI-2007 model respectively.

The results show good correlation between CADI-foF2 and IRI-foF2 during 2003-2006 period with deviations less than 15%. The big differences in this phase only occur during the minimum and maximum time of foF2 during the day (about 20%). In the period 2009 – 2012, good correlation is seen for morning time, before the first peak of foF2 (~ 10 LT) with deviations about 10% (except in 2012). However, after that, the difference is quite large, IRI-foF2 values are higher than CADI-foF2 by 25% and 30%. The deviation shows a growing trend, especially in 2012.

Figure 3 presents the comparision of seasonal variations between CADI-foF2 and IRI-foF2 during solstices (January, July) and equinoxes (April, October). The results show, that the foF2 values were highest during the equinoxes and lowest during the solstices. We can see a good correlation between two data sets for the second half of 23 solar cycle and a large deviation for the first half of the 24 solar cycle. The cause of the low discrepancy during the 23 solar cycle is the improvement of the model with the updated monitoring data in the last years to the IRI-2007 version. However, the large difference in cycle 24 indicates that IRI data have been estimated too high and need to be adjusted down to match the actual data.

Figure 4 presents the correlations between CADI-foF2 and IRI-foF2 for 2003 - 2012 years. The x axis denotes observed data, the y axis represents the IRI prediction values. The results show a good correlation between observations and model data (R > 0.9, k > 0.8).

The results also show an interesting reverse relationship between the k coefficient and the solar activity (figure 5). For the years of low solar activity with SSN < 40 (2006 - 2010), k > 1 that means IRI-foF2 values are higher than observed data. For the years with SSN > 40 (2003, 2004, 2005, 2011 and 2012), k < 1 means that the IRI-foF2 values are smaller than the observations.

The R coefficient tends to decrease in recent years, i.e. large deviation between the observed data in HCM and IRI predictions. This suggests the IRI model should be adjusted.

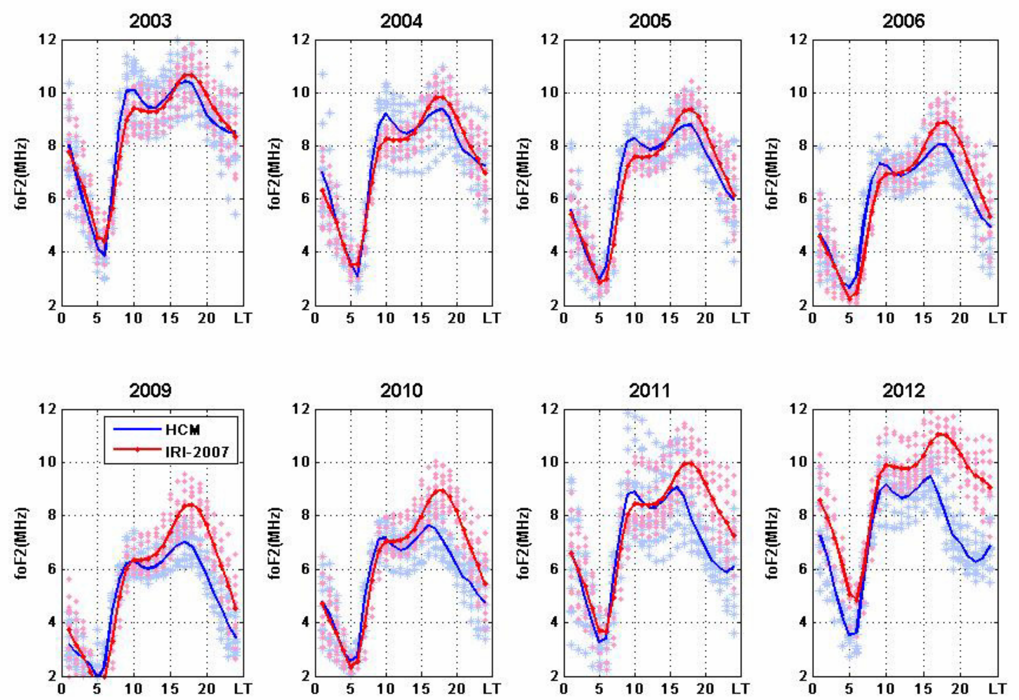

Figure 2: Diurnal variations of CADI-foF2 at HCM and IRI-foF2 during 2003 - 2012

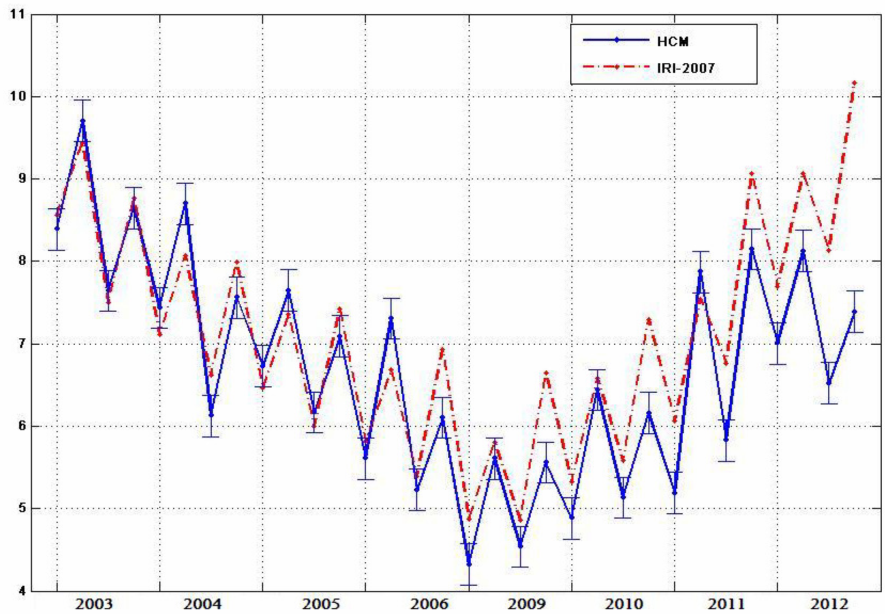

Figure 3: Seasonal variations of CADI-foF2 at HCM and IRI-foF2 during 2003 - 2012

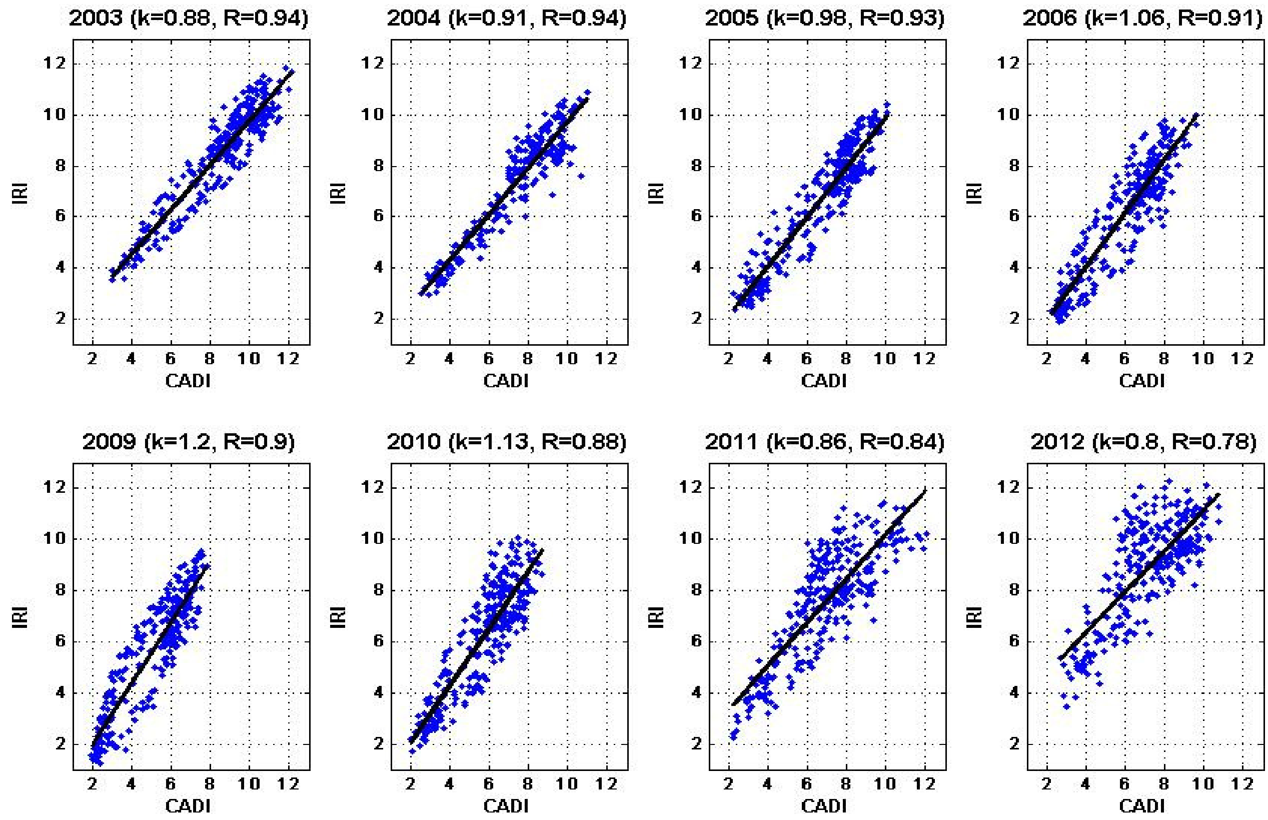

Figure 4: Correlations between CADI-foF2 and IRI-foF2

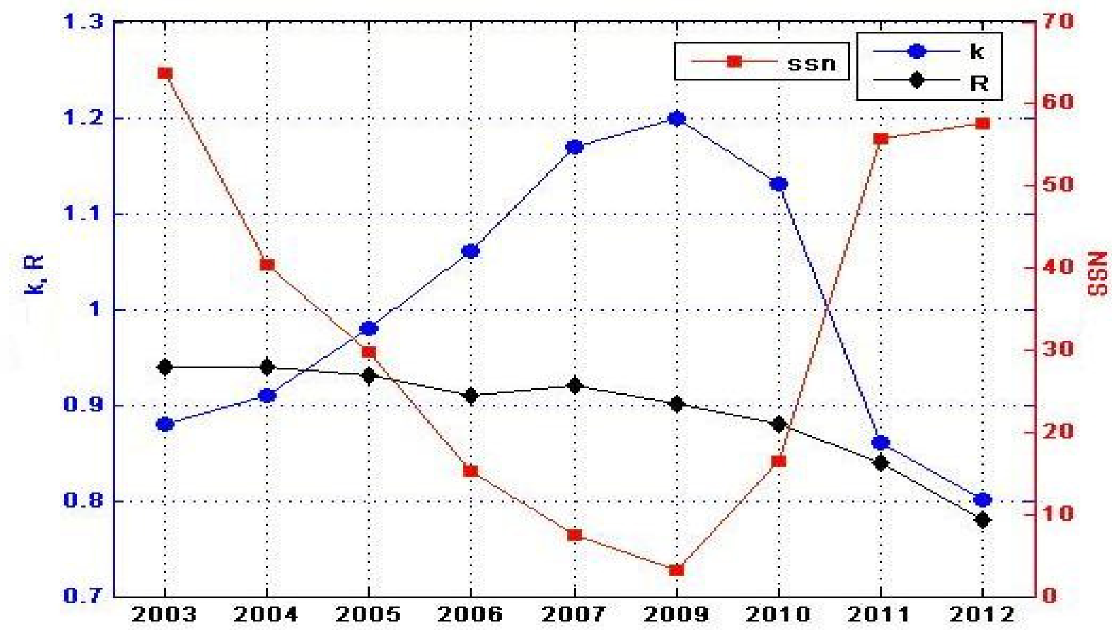

Fig 5: Variations of the k, R and Sunspot Number during 2003 - 2012

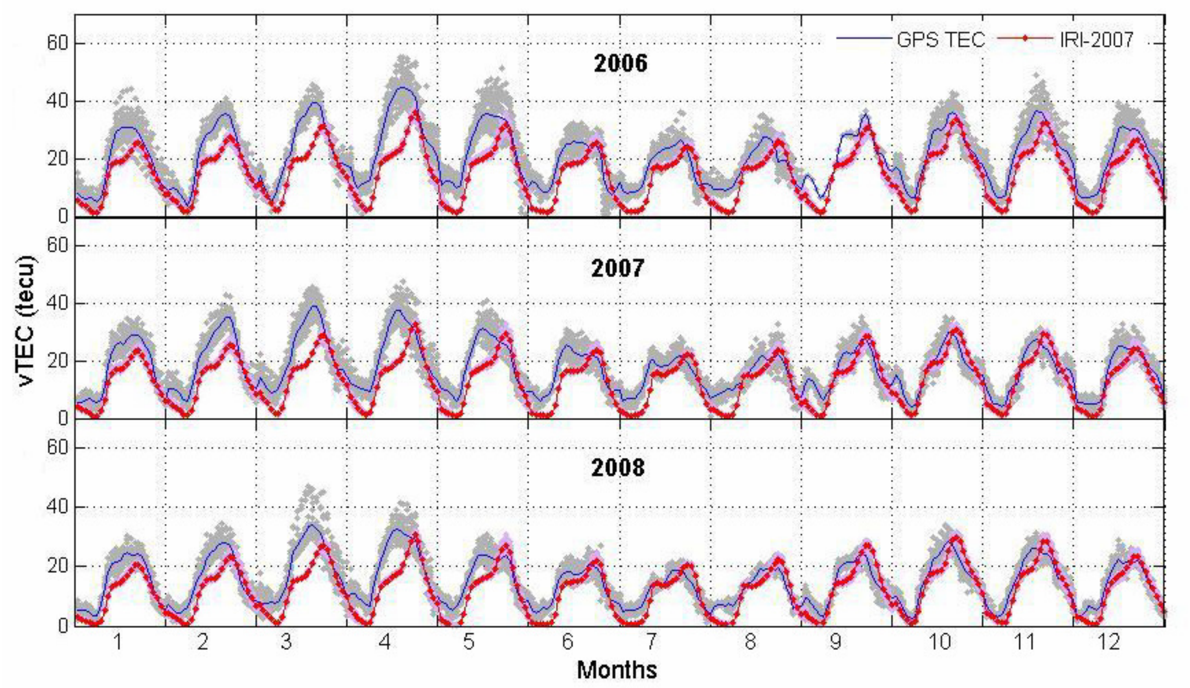

Figure 6a: Daily and monthly TEC variations observed over HCM and IRI-TEC during 2006 – 2008

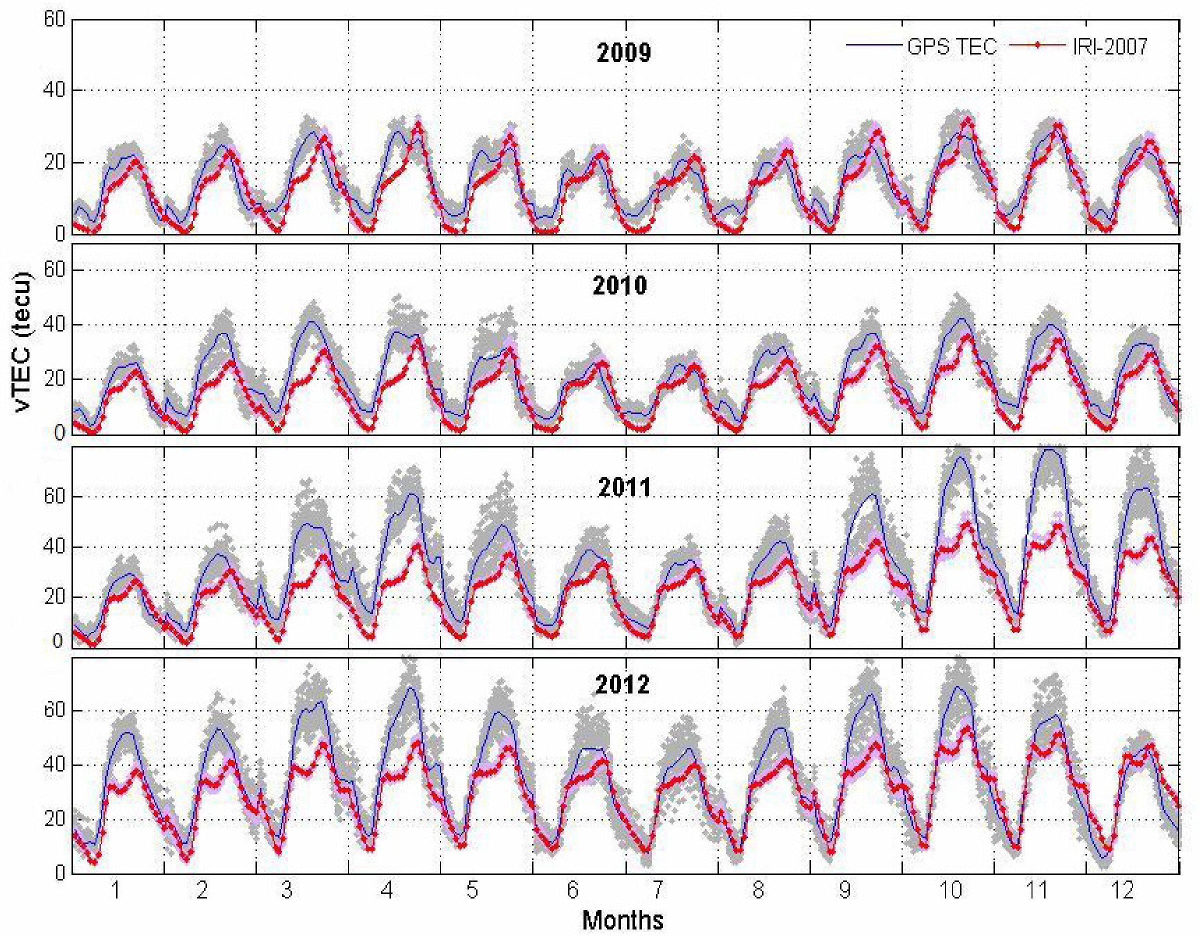

Figure 6b: Daily and monthly TEC variations observed over HCM and IRI-TEC during 2009 – 2012

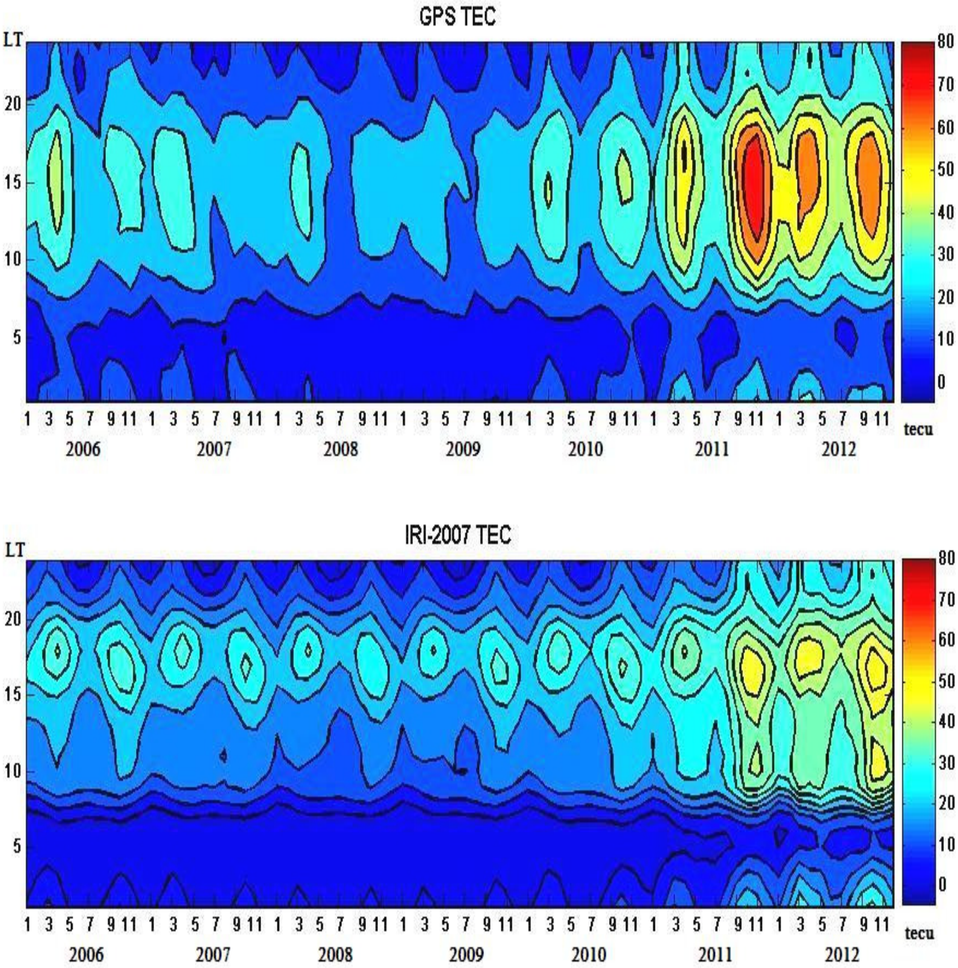

Figure 7: Diurnal and seasonal variations of GPS-TEC and IRI-TEC during 2006 – 2012

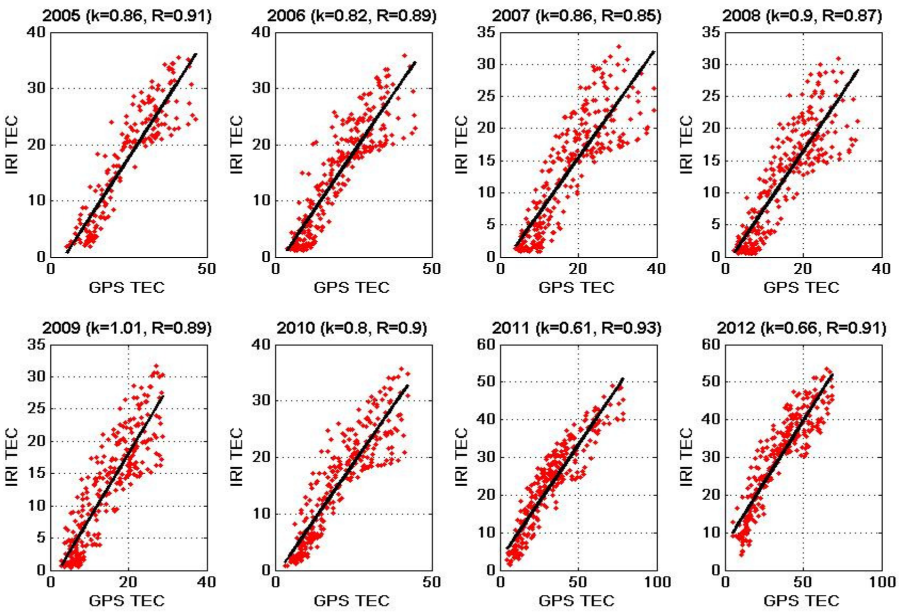

Figure 8: Correlations between GPS-TEC and IRI-TEC during 2005 – 2012

The results of the comparision between GPS-TEC and IRI-TEC

Figures 6a and 6b present the variations of TEC data collected by the GPS receiver at HCM observatory and TEC values calculated from IRI-2007, during decreasing phase of solar activity 2006- 2008 and increasing phase 2009 - 2012, respectively. The data calculated daily and monthly average. Monitoring data showed that morphological variation of GPS-TEC has only one peak near noon, and not two peaks in the morning (~ 10 LT) and in the afternoon (~ 13 LT) as the model shows. The most suitable morphological variation between monitoring and model data is during the solar activity minima.

The results showed that the TEC values are higher during the equinoxes and lower during the solstices. Differences between GPS-TEC and IRI-TEC appears in the early morning hours, from 0 am to 5 am local time and the deviations sometimes rise to more than 50%. At these moments, the minimum IRI-TEC value showed ~ 0.3 tecu, while the GPS-TEC value is ~ 3 tecu. This result is consistent with the results of Adewale who compared the TEC value received in Lagos, Nigeria (6.5 N, 3.4 E) in 2009 (Adewale et al., 2011), and Kenpankho's comparison results using GPS data collected in Chumphon, Thailand (10.72 N, 99.37 E) for 2004 - 2006 (Kenpankho et al., 2011).

The statistical results also show that, in the years with average solar activity (2005, 2006, 2010, 2011, 2012), the GPS-TEC is higher than IRI-TEC for almost all the time during the day. For the years with weak solar activity (2007 - 2009), the GPS-TEC is higher than IRI-TEC, in the period from 0 LT to 15 LT. After 15 LT, the GPS-TEC values are smaller than IRI-TEC.

Figure 7 illustrates the diurnal and seasonal variation of GPS-TEC and IRI-TEC. The x axis represents the months from 2006 to 2012. The y axis denotes the 24-hour local time (LT). Both data sets showed that the TEC peaks from March to May, and from September to November. A clear difference between two data sets is the peak of the GPS-TEC appearing during 10 LT to 20 LT while the IRI-TEC showed peaking during 15 LT to 20 LT. The variation of TEC also show a dependancy on solar activity, however, the IRI-TEC variations changed more slowly with solar activity.

Figure 8 presents the correlations between GPS-TEC and IRI-TEC during 2005 – 2012. We can see good correlations with the coefficients R and k > 0.8, except for 2011 (k = 0.61) and 2012 (k = 0.66), when the GPS-TEC is quite large compared with IRI-TEC. The difference focuses on March, April, September, October, November and December (showed in figure 6b). The main reason for these differences may be due to the solar activity rising in these months and leading to the high TEC but there was no corresponding IRI adjustment. In the years with low solar activity (2007, 2008, 2009, 2010), the GPS-TEC and IRI-TEC have very good correlations. This result is consistent with the results of Scida et al. (2011) who summarized the feasibility of applying the IRI-2007 TEC calculations for South America.

Conclutions

1. The results show very good diurnal correlations between observed foF2 and IRI-foF2 for the decreasing solar activity period 2003 - 2006, with a deviation < 15%. A difference of about 20% showed only at minima and maxima of foF2. For the increasing period 2009 – 2012, good correlation is in the morning time before the foF2 reached its peak at about 10 LT, with a deviation about 10% (except 2012). After 10 LT, the IRI-foF2 values rose up and the deviation is about 25% to 30%.
2. During the years with low solar activity (SSN < 40), IRI-foF2 values are higher than the observed data, and vice versa for the years with SSN > 40. This is a note for correcting the IRI model applying for Vietnam.
3. The correlation between GPS-TEC and IRI-TEC values generally is good with coefficients k > 0.8 and R > 0.9 for the period 2006 - 2010. The worst relationship were March, April, September, October, November and December 2011, corresponding to periods when the TEC gradients are highest.
4. The noon's TEC decline phenomenon was not evident in the monitoring data over Ho Chi Minh. This phenomenon is observed only in a few months from April to September compared with the results of IRI-TEC.
5. The peak of the GPS-TEC occurred at about 14 - 15 LT. High GPS-TEC values appeared during 10 LT to 20 LT, while the IRI-TEC showed highs during 15 LT to 20 LT. The large differences between GPS-TEC and IRI-TEC appeared in the early morning hours (0 LT – 5 LT) and the deviations sometimes rose to more than 50%. The minimum IRI-TEC in the early morning time showed about 0.3, while the minimum GPS-TEC observed about 3 tecu. We think that IRI model needs to be recalibrated for Vietnam.

We hope that these results and related works in the future will provide useful information for the construction of the Global Space Weather Model.

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